INFLUENCE OF BOUNDARY CONDITIONS ON PROPERTIES OF STALL

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Introduction

To develop new ways of flow wing controlling, the study of the three-dimensional vortex structure of separated flows and the influence of an external flow on this structure parameters is an urgent problem. The first data of the picture of the flow separating on a low-aspect-ratio wing were obtained in [1, 2], where it was found that a complex vortex flow with an extensive circulating zone appeared in the middle part of the wing. It is known that the distinctive feature of large-scale vortexes arising in separation areas is their high susceptibility to external disturbances [3 – 5], which enables one to control the flow acting on these vortexes. However, for the same reason, the disturbances occurring in the area of separation from ledges on a model surface, or due to the flow from the bottom wing surface to the top one, can essentially influence the phenomenon under consideration.

The existence of the complex vortex structures associated with the flow separation has also been demonstrated in [6 – 9]. The authors, however, have neither distinguished the leading-edge global separation (stall) from the downstream turbulent separation, nor studied the possible differences in these flows topology.

The necessity of studying the disturbances influence on the stall is caused by the fact that stall elimination increases significantly the wing lift force and reduces its drag. The previous results have shown that the external influence essentially changes the spatial structure of such a flow and in some cases results in the stall complete elimination. The examination of disturbances development and flow structure reorganization allows one to find the most effective ways of the separation control.

The resent paper investigates what kinds of structure changes appear due to variation in flow conditions on model sides. The vertical plates were installed on the model end faces and they interfered the flow from the bottom wing surface to the top one. Visualization of flow pictures for the various variants of the flow was performed. Such researches can bring large advantage in perfection of low-speed airplanes aerodynamic characteristics, with the purpose to carry out a comprehensive control of the flow and also to prevent occurring of adverse flow modes.

The technique of experiments

The presearches were carried out in subsonic wind tunnel MT-324 in Institute of Theoretical and Applied Mechanics of SB RAS, Novosibirsk. This installation represents a wind tunnel of a closed type and can operate with an opened or closed test section. The walls of installation are wooden. Air moves with the help of a fan initiated by an electric engine. A free flow turbulence degree in the wind tunnel was about 0.1 %. A flow of the model top surface of a a rectangular wing was studied. The model was made of wood and had an unsymmetrical profile with relative thickness of 15 % and chord b = 102 mm. The span of model is of 200 mm, aspect ratio is 2. The model was established in the open test section of the wind tunnel under the angles of attack of 16^o or 26^o. During the experiment the angle of attack was not changed. The distance from the beginning of the test section to the model leading edge was of 60 mm. The flow velocity was U_0 =14 m/s, and chord Reynolds number was of $0{,}9 \cdot 10^5$. The experiments were carried out with the help of flow picture visualization on the wing surface by "soot - oil"

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
23 Aug 2002	N/A	-

Title and Subtitle Influence of Boundary Conditions on Properties of Stall	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Institute of Theoretical and Applied Mechanics Institutskaya 4/1 Novosibirsk 530090 Russia	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) EOARD PSC 802 Box 14 FPO 09499-0014	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes See also ADM001433, Conference held International Conference on Methods of Aerophysical Research (11th) Held in Novosibirsk, Russia on 1-7 Jul 2002	
Abstract	
Subject Terms	
Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU
Number of Pages 4	

method (a mixture of titanium dioxide powder and kerosene) coatings with the subsequent photographing of pictures obtained.

Some investigations were carried out at a high level of free steam turbulence which was of 1% and was produced by a turbulizing grid. The grid was made of a 0.3 mm-diameter wire. The cell size was of 2.3 mm.

The results of experiments

Figures 1 - 6 present some experimental results, showing the influence of the boundary conditions on the flow topology at the stall. Figure 1 shows the flow pictures on the wing surface with the vertical plates on each side, and Fig. 2 – on the wing surface without such plates. The angle of attack of the model was of 16°, the flow velocity 14 m/s. Flow separation (stall) takes place on the model near the leading edge, and the area of separation occupies the whole model surface. A reverse flow appears in the separation area on a model surface from the trailing edge to leading one. (Hereinafter the flow direction is downstream). The separation line is evident in a front part of the model as a light strip along the span. It shows that the two-dimensional separation occurs in that place. But the flow is three-dimensional in the separation area. The complex structures appear which present large-scale pair vortexes, rotating in wing planes. The form and quantity of these vortexes depends on the flow conditions on the model edges. One pair of such vortexes of large size occurs on a wing with vertical plates (one vortex to the right and left from the wing axis of symmetry).

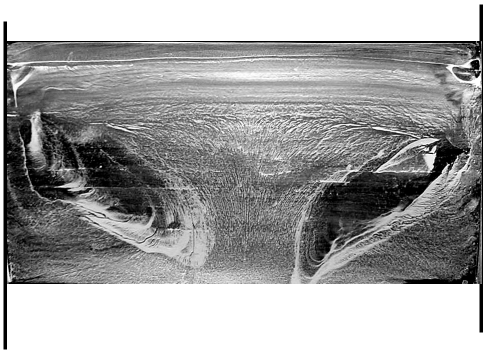

Fig. 1.

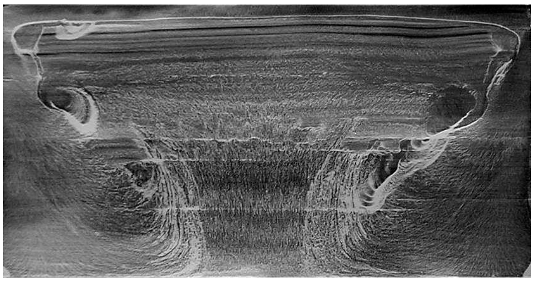

Fig. 2.

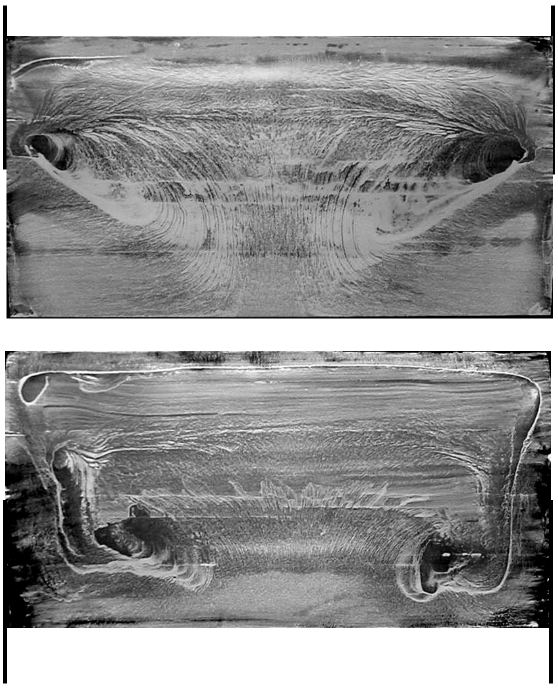

Fig. 3.

If vertical plates are removed, the flow picture of current changes essentially (see Fig. 2). The flow separation occurs in the same place, but the large-scale vortexes in the separation area have another form and sizes. Now there are two pairs of vortexes instead of one. The flow symmetry is still kept. Thus, the flow from the bottom surface on the top one changes significantly the vortexes picture of flow on

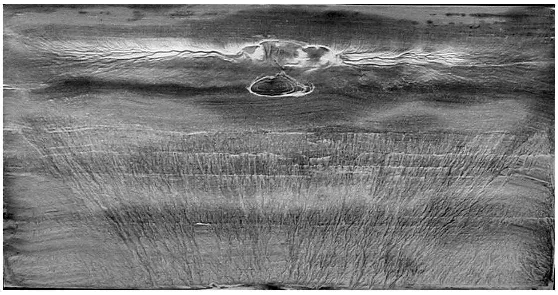

Fig. 4.

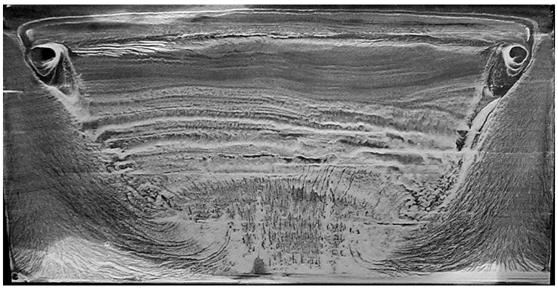

Fig. 5.

the whole wing surface. Fig. 3 demonstrates the results of visualization for the cases when the plates were established either in the front or in the back part of the wing. It is seen that the flow pictures differ dramatically. And the plates in the wing front part present practically the same flow picture as the plates occupying the whole side edge (see Fig. 1). The plates in the back part of the wing give absolutely different flow picture.

The stall is strongly influenced by a free stream turbulence degree. Figure 4 presents the results of visualization with a high degree of the free stream turbulence which was of 1 %. Such a degree of the free stream turbulence was achieved with the help of turbulizing grid which was installed before the test section of wind tunnel. It has turned out that when the angle of attack is of 160 like the previous experiments were done, the high external turbulence results in flow reattachment. A narrow separated bubble appears in the front part of the wing, below it the attached flow occurs on the model surface.

Figure 5 shows the results of the external turbulence influence on the stall at rather bigger angle of attack which was equal to 26°. With such an angle of attack the high external turbulence does not cause reattachment. The stall is kept on the wing, but its vortex structure changes. In the model front part there is a stagnation zone in a form of a narrow strip along the span. The focuses of vortexes become less in size and are moved together closer to the leading edge. Earlier such an influence of the high turbulence on the stall was mentioned in [10] for a wing of low aspect ratio $\lambda = 0.9$. The picture presented in Fig. 5 correspond with those from [10]. Thus, our results show that the influence of the external turbulence is identical for the wings of various aspect ratio.

Conclusion

The described experiments present a part of the work on systematic study of a vortexes three-dimensional nature of the separated streams. The results of he investigations have shown the variety of the forms of a vortex flow with the stall on straight wings. Both the common properties of such flows which appear in forming large-scale pair vortexes rotating in planes of a wing and the differences in flows topology due to boundary condition variation have been found. The existence of such vortexes opens a new direction in study of the flow separation phenomenon, since it essentially changes a physical picture of the flow which originally was two-dimensional, and requires creation of a new model of the separation phenomenon, in view of its three-dimensionality.

The results of experiments can find the practical application to improve the flow of low velocity airplanes.

Acknowledgements. The work was supported by Russian Foundation for Basic Research (Grants Nos. 01-01-00828 and 00-15-96164).

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